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Evaluation of yield-related traits in linseed (*Linum usitatissimum* L.) using correlation and path coefficients

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Abstract
In order to study the correlation and analysis of path coefficients of yield and its contributing features in linseed (*Linum usitatissimum* L.), a field experiment was carried undertaken during the Rabi season of 2023. At the Research Farm, Department of Genetics and Plant Breeding, College of Agriculture, Latur, 40 different genotypes were assessed using a randomised block design with two replications. Days to 50% flowering, days to maturity, plant height (cm), seed production per plant (g), harvest index (%), oil content (%), number of branches per plant, number of capsules per plant, number of seeds per capsule, and 1000-seed weight (g) were all measured. According to correlation research, characteristics like plant height, number of branches per plant, number of capsules per plant, and harvest index significantly increased seed yield per plant, showing that these factors may be useful for increasing productivity. Days to 50% flowering, plant height, number of branches per plant, and oil content all showed significant direct effects on seed output, indicating their direct influence on productivity, according to path coefficient analysis. Linseed breeding programs aimed at increasing seed production may find these findings useful as they highlight the significance of these qualities in criteria for selection.

Keywords: Linseed, correlation coefficient, path analysis, genetics

Introduction

The genus name *Linum* is derived from the word *lin*, meaning "thread," reflecting the plant's traditional association with fiber production. The species epithet *usitatissimum* originates from Latin, signifying "most useful" highlighting the plant's multifaceted applications. When cultivated for its oil-rich seeds, the crop is commonly referred to as flaxseed or linseed whereas its fiber-producing form is known as fibre flax or simply flax, particularly within European contexts. (Vaisey-Genser and Diane, 2003) [12]. It thrives on fertile, medium-to-heavy, well-drained soils, particularly silty loam, clay loam and silty clays. During the blooming stage, high temperatures (over 32^0C) combined with moisture stress limit the production of seeds. The plant features narrow, lance-shaped leaves and produces small, blue or white flowers. The seeds of linseed are small, flat and oval in shape with a hard outer shell that protects the inner oil-rich core. This crop is grown in three different ecosystems: irrigated, rainfed and uterine. Linseed is a versatile winter (*rabi*) oilseed crop, cultivated primarily for its oil.

Because it contains a lot of omega fatty acids, especially omega-3 and omega-6, linseed is known for having an outstanding nutritional profile. Alpha-lino (ALA), the antioxidant eicosatetraenoic (EPA) and docosahexaenoic acid or DHA are the three essential fatty acids that make up the omega-3 group. It is well recognized that these acids support cardiovascular health. Among these, linseed is especially rich in ALA, with alpha-linolenic acid accounting for approximately 57% of its total fatty acid composition, while linoleic acid constitutes around 16%. In addition to its beneficial lipid profile, linseed also offers substantial amounts of dietary fibre, protein, and oil, making it a valuable functional food. Two primary types of linseed are cultivated for consumption—brown and golden (also referred to as yellow)—both widely used in flaxseed products. About 41 percent fat, 20 percent protein, 28 percent dietary fibre, 7.7 percent moisture and 3.4 percent ash the mineral-rich residue left over after combustion are the normal contents of brown flaxseed. Notably, an inverse relationship exists between oil and protein content; as oil content increases, protein levels tend to decrease. The seed's oil content generally ranges between 33% and 45%. (Gill, 1987) [5]. Flaxseed is used in various baked and fried products, such as bread and bagels, though its direct human consumption in these forms is relatively limited. Flax fiber is highly valued for its strength and durability, surpassing that of cotton, rayon or wool. It can be categorized into four types: multicellular fiber, cellulose, bast and natural. Nutrient-dense flax contains calcium (170 mg/100 g), phosphorus (370 mg/100 g), potassium, manganese, sterols, phospholipids (0.11-0.21%) and waxes (0.012-0.450%). The oil cake from flaxseed has germicidal properties, making it useful as organic manure to enhance soil fertility and deter pests. It also serves as a nutritious feed for dairy cattle, containing approximately 5% nitrogen, 1.4% phosphorus (P2O5) and 1.8% potassium (K2O).

Correlation coefficient estimates are often inaccurate on their own because the effects of yield component traits can cancel each other out. Both the direct and indirect impacts of distinct components on a complex characteristic can be examined with the help of path coefficient analysis (Naik *et al*., 2016) [4]. This approach reveals how yield component traits contribute to complex traits, while correlation analysis provides a more comprehensive understanding of each component's influence on the overall expression of the complex character.

Materials and Methods

The present investigation was carried out during the *Rabi* season of 2023-2024 at the Experimental Farm of the Department of Genetics and Plant Breeding, College of Agriculture, Latur (Maharashtra). A total of 40 linseed (*Linum usitatissimum* L.) genotypes were evaluated using a randomized block design (RBD) with two replications. Each genotype was sown in a plot measuring 5 × 0.12 m², maintaining a row-to-row spacing of 30 cm and plant-to-plant spacing of 5 cm to ensure optimum plant population. Recommended agronomic practices were uniformly applied throughout the growing period and appropriate plant protection measures were implemented as needed to maintain a healthy crop stand. Observations were recorded on ten quantitative traits: days to 50 per cent flowering, days to maturity, plant height (cm), number of branches per plant, number of capsules per plant, number of seeds per capsule, 1000-seed weight (g), harvest index (%), oil content (%) and seed yield per plant (g).

Results and Discussion

The most accurate way to analyze the link between significant yield components is to use correlation in conjunction with path analysis. These methods were employed in the breeding effort to take advantage of the potential yield to increase the productivity of linseed and creating superior types with higher yields. The reciprocal link between the factors is known as correlation and it helps to identify the best practices for selecting superior genotypes.

The correlation analysis determined that seed yield per plant exhibited a highly significant and positive genotypic relation with number of branches per plant (r = 0.9042), number of capsules per plant (r = 0.9302), and harvest index (r = 0.9276). A significant positive association was also observed with plant height (r = 0.3699), while the association with oil content was positive but non-significant (r = 0.1517). Conversely, negative and non-significant genotypic character association were recorded for days to 50 per cent flowering (r = -0.065), days to maturity (r = -0.1255), number of seeds per capsule (r = -0.0598) and 1000 seed weight (r = -0.1413).

At the phenotypic level, seed yield per plant showed highly significant and positive correlation with plant height (r = 0.3716), number of branches per plant (r = 0.8123), number of capsules per plant (r = 0.8506), and harvest index (r = 0.8426). The correlation with oil content remained positive but non-significant (r = 0.1451). Traits such as days to 50% flowering (r = -0.0499), days to maturity (r = -0.1149), number of seeds per capsule (r = -0.0208) and 1000 seed weight (r = -0.1222) demonstrated negative and non-significant phenotypic correlations with seed yield per plant. These findings indicate that the number of branches per plant, number of capsules per plant and harvest index are the most influential traits contributing to seed yield and should be considered in selection strategies for yield improvement in linseed.

Correlation coefficient analysis demonstrated that seed yield per plant was positively and highly significantly associated with plant height, number of branches per plant, number of capsules per plant and harvest index at both genotypic and phenotypic levels. These traits showed consistent and strong positive relationships with seed yield, suggesting their potential as reliable selection criteria in breeding programs aimed at enhancing productivity (Table 1). Similar trends have been reported by Tadesse *et al*. (2009) [10], Gauraha *et al*. (2011) [3], Patial *et al*. (2018) [9], Meena *et al.* (2020) [7] and Patel *et al*. (2023) [8] thereby reinforcing the importance of these characters in yield improvement strategies.

Oil content displayed a positive but non-significant association with seed yield per plant indicating that selection for oil content may require independent improvement strategies, as its enhancement may not occur through indirect selection via seed yield. These findings are consistent with results reported by Meena *et al*. (2020) [7].

On the other hand, traits such as days to 50 per cent flowering, days to maturity, number of seeds per capsule and 1000 seed weight showed negative and non-significant association with seed yield at both genotypic and phenotypic levels. These observations similar with earlier studies conducted by Meena *et al*. (2020) [7] and Gavhane (2021) [4].

Although character association analysis helps identify traits associated with seed yield, it does not distinguish between direct and indirect impact of these variables. Hence, to better understand the relative contribution of individual traits and to formulate effective selection strategies, path coefficient analysis as proposed by Dewey and Lu (1959) [2] was employed in the present study.

The path coefficient analysis (Table 2) provided further insights into the direct and indirect impact of various characters on seed yield per plant. At both genotypic and phenotypic levels, traits such as days to 50 per cent flowering, plant height, number of branches per plant and oil content exhibited a positive direct impact on seed yield. These traits also showed strong positive correlations with yield reinforcing their significance in direct selection strategies aimed at improving seed productivity in linseed.

In contrast, traits including days to maturity, number of seeds per capsule, number of capsules per plant, 1000 seed weight and harvest index exhibited negative direct effects on seed yield per plant. Although some of these traits may still contribute positively through indirect effects, their negative direct influence suggests that selection must be approached with caution to avoid unintended yield reductions. Therefore, a balanced selection approach is necessary to optimize overall performance without compromising yield potential. These findings are in agreement with previous studies by Chaudhary *et al.* (2016), Kasana *et al.* (2018), Thakur *et al.* (2020), Meena *et al.* (2020) [7] and Gavhane (2021) [4] who also reported similar patterns of direct and indirect impact on linseed.

Table 1: Estimates of genotypic correlation coefficients for yield and yield contributing traits in Linseed.

Characters	Days to 50 per cent flowering	Days to maturity	Plant height (cm)	Number of branches per plant	Number of capsules per plant	Number of seeds per capsule	1000 Seed weight (g)	Harvest index (%)	Oil content (%)	Seed yield per plant (g)
Days to 50% flowering	1.000	0.6868 **	0.3355 *	-0.1359	-0.0591	0.1856	-0.0170	-0.0886	0.4198 **	-0.0650
Days to maturity		1.000	0.0511	-0.1092	-0.0571	0.2980	0.0236	-0.1083	0.5506 **	-0.1255
Plant height (cm)			1.000	0.2385	0.3114*	0.1414	0.2374	0.3217 *	0.4216 **	0.3699 *
No. of branches per plant				1.000	0.9964 **	-0.0698	-0.1656	0.9257 **	0.0972	0.9042**
Number of capsules per plants					1.000	0.0022	-0.0927	0.9589 **	0.1978	0.9302 **
Number of seeds per capsules						1.000	0.4000 *	0.0122	0.3625 *	-0.0598
1000 seed weight (g)							1.000	-0.1793	0.2122	-0.1413
Harvest index (%)								1.000	0.1256	0.9276 **
Oil content (%)									1.000	0.1517
Seed yield per plant (g)										1.000

* and ** significant at 5 and 1 per cent respectively

Table 2: Estimates of phenotypic correlation coefficients for yield and yield contributing traits in Linseed.

Characters	Days to 50 per cent flowering	Days to maturity	Plant height (cm)	Number of branches per plant	Number of capsules per plant	Number of seeds per capsule	1000 Seed weight (g)	Harvest index (%)	Oil content (%)	Seed yield per plant (g)
Days to 50% flowering	1.000	0.6732**	0.3339**	-0.1197	-0.0549	0.1769	-0.0202	-0.0888	0.3954**	-0.0499
Days to maturity		1.000	0.0491	-0.1089	-0.0509	0.2693*	0.0247	-0.1046	0.5238**	-0.1149
Plant height (cm)			1.000	0.2312 *	0.2996**	0.1403	0.2285 *	0.3121**	0.3916 **	0.3716 **
No. of branches per plant				1.000	0.9423**	-0.0493	-0.1827	0.8227**	0.0987	0.8123**
Number of capsules per plant					1.000	-0.0349	-0.0898	0.8509**	0.1688	0.8506**
Number of seeds per capsule						1.000	0.3535**	-0.0039	0.3081 *	-0.0208
1000 seed weight (g)							1.000	-0.1856	0.1837	-0.1222
Harvest index (%)								1.000	0.1085	0.8426**
Oil content (%)									1.000	0.1451
Seed yield per plant (g)										1.000

Table 3: Direct and indirect effects (genotypic) of different characters on seed yield per plant in Linseed.

Characters	Days to 50 per cent flowering	Days to maturity	Plant height (cm)	Number of branches per plant	Number of capsules per plant	Number of seeds per capsule	1000 Seed weight (g)	Harvest index (%)	Oil content (%)	Seed yield per plant (g)
Days to 50 per cent flowering	0.1448	0.0994	0.0486	-0.0197	-0.0086	0.0269	-0.0025	-0.0128	0.0608	-0.0650
Days to maturity	-0.1044	-0.1520	-0.0078	0.0166	0.0087	-0.0453	-0.0036	0.0165	-0.0837	-0.1255
Plant height (cm)	0.0427	0.0065	0.1272	0.0303	0.0396	0.0180	0.0302	0.0409	0.0536	0.3699 *
No. of branches per plant	-0.2450	-0.1968	0.4300	0.5227	0.7963	-0.1258	-0.2985	0.8131	0.1752	0.9042**
Number of capsules per plant	0.0268	0.0259	-0.1411	-0.4514	-0.4530	-0.0010	0.0420	-0.4559	-0.0896	0.9302 **
Number of seeds per capsule	0.0098	0.0157	0.0074	-0.0037	0.0001	0.0525	0.0210	0.0006	0.0190	-0.0598
1000 seed weight (g)	0.0002	-0.0002	-0.0025	0.0017	0.0010	-0.0042	-0.0104	0.0019	-0.0022	-0.1413
Harvest index (%)	0.0329	0.0402	-0.1194	-0.3734	-0.3736	-0.0045	0.0666	-0.3712	-0.0466	0.9276 **
Oil content (%)	0.0274	0.0359	0.0275	0.0063	0.0129	0.0236	0.0138	0.0082	0.0652	0.1517
Seed yield per plant (g)	-0.0650	-0.1255	0.3699*	0.9042**	0.9302**	-0.0598	-0.1413	0.9276**	0.1517	1.000

Table 4: Direct and indirect effects (phenotypic) of different characters on seed yield per plant in Linseed.

Characters	Days to 50 per cent flowering	Days to maturity	Plant height (cm)	Number of branches per plant	Number of capsules per plant	Number of seeds per capsule	1000 Seed weight (g)	Harvest index (%)	Oil content (%)	Seed yield per plant (g)
Days to 50 per cent flowering	0.0523	0.0352	0.0175	-0.0063	-0.0029	0.0092	-0.0011	-0.0046	0.0207	-0.0499
Days to maturity	-0.0515	-0.0765	-0.0038	0.0083	0.0039	-0.0206	-0.0019	0.0081	-0.0401	-0.1149
Plant height (cm)	0.0212	0.0031	0.0634	0.0147	0.0190	0.0089	0.0145	0.0198	0.0248	0.3716 **
No. of branches per plant	-0.0122	-0.0111	0.0235	0.1017	0.0958	-0.0050	-0.0186	0.0941	0.0100	0.8123**
Number of capsules per plants	-0.0178	-0.0165	0.0971	0.3055	0.3241	-0.0113	-0.0291	0.3108	0.0547	0.8506**
Number of seeds per capsule	-0.0017	-0.0027	-0.0014	0.0005	0.0003	-0.0099	-0.0035	0.0000	-0.0030	-0.0208
1000 seed weight (g)	-0.0002	0.0003	0.0028	-0.0023	-0.0011	0.0044	0.0124	-0.0023	0.0023	-0.1222
Harvest index (%)	-0.0471	-0.0563	0.1653	0.4904	0.5079	-0.0020	-0.0983	0.5297	0.0575	0.8426**
Oil content (%)	0.0072	0.0096	0.0071	0.0018	0.0031	0.0056	0.0033	0.0020	0.0182	0.1451
Seed yield per plant (g)	-0.0499	-0.1149	0.3716**	0.8123**	0.8506**	-0.0208	-0.1222	0.8426**	0.1451	1.000

Conclusion

Correlation analysis revealed that seed yield per plant exhibited a significant positive association both at genotypic and phenotypic levels with plant height, number of branches per plant, number of capsules per plant and harvest index. These characters, therefore, appear to be key contributors to seed yield and can be considered important selection criteria in linseed improvement programs. In contrast, traits such as days to 50 per cent flowering, days to maturity, number of seeds per capsule and 1000-seed weight showed a negative correlation with seed yield per plant, suggesting a limited or unfavorable influence on yield enhancement. Path coefficient analysis further supported these findings by indicating that plant height, number of branches per plant, days to 50 per cent flowering and oil content had a strong and positive direct impact on seed yield per plant. The combination of high direct effects and positive correlations for these traits underscores their relevance in direct selection strategies aimed at improving seed yield in linseed.

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